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STUDY OF THE CORRESPONDENCES DISTRIBUTION OF VEHICLE TRAFFIC ON THE ROAD NETWORK OF CITIES

Summary. *The problems of traffic management in large cities are complicated as the increase in traffic volume far exceeds the road network capacity. It leads to saturation of the road network, which negatively affects its functioning. This article analyzes the state of the art of improving the quality of road traffic by predicting the size of traffic after the implementation of traffic management measures. While the issue of modeling traffic flow parameters based on technological factors has been sufficiently studied, the problems of considering the human factor need to be clarified. The object of study is traffic flow on the city's road network. The criteria used by drivers to compare the characteristics of alternative traffic routes were identified based on the field study results. Based on the data obtained, the parameters of alternative routes that drivers choose when driving on the road network are formed. According to the survey results, the most significant factor is the minimum mileage along the route. Deviations from the shortest route were determined to determine the patterns of distribution of correspondence of non-route vehicles along alternative routes. It made it possible to define the distribution of transport correspondence along alternative routes. Since the process under consideration is probabilistic, the law of distribution of a random variable was determined. After having determined the law of distribution of a random variable for the data obtained, the calculations showed that the change in the random variable is well described by the gamma distribution. It was determined that the share of transport correspondence that will be carried on them decreases as the length of the route deviates from the shortest one. The obtained results make it possible to predict road network congestion by modeling the distribution of traffic flows. In further research, it would be advisable to analyze the distribution of transport correspondence by other criteria.*

Keywords: *traffic volume, traffic flow, driver, distance, route, speed of movement.*

1. INTRODUCTION

An increase in the motorization level and, therefore, traffic volumes on the streets and roads of the city leads to saturation of the road network, which negatively affects its functioning. It is necessary to take measures to improve road traffic to maintain the parameters needed to ensure its efficiency and safety. The solution to this problem is possible by bringing the parameters of the road network in line with the values of traffic flows, constantly improving the means and systems of traffic management. Any developments created to improve traffic quality are based on a forecast of traffic volumes after their implementation.

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Based on this information, the effect can be assessed, and a conclusion can be made about the feasibility of the proposed measures. The importance of the results and the significant material costs associated with implementing these measures place high demands on the reliability of traffic flow forecasts on the road network. The traffic congestion on the city's road network is determined by the size and direction of traffic flow correspondences. Considering the distribution patterns of transport correspondences along alternative routes when overlaying flows on the network will allow modeling in accordance with the processes occurring in the network. It will help to increase the reliability of the forecast results, allowing for a more balanced determination of the requirements for the development of the road network and outlining management impacts to meet them. Measures effectiveness can be assessed by modeling the parameters of traffic flows before and after implementation. One of the methods for determining the amount of flow at sections and intersections is the overlay of traffic on the transport network, which is made along different routes [1].

2. RESEARCH STATEMENT

A traffic flow consists of individual vehicles with different dynamic characteristics and is driven by drivers with different qualifications [2]. The main parameters of the traffic flow are related to the capabilities, needs, and characteristics of the driver and the vehicle, which together form a discrete element of the model [3].

All vehicles moving in the traffic can be divided into route vehicles, which adhere to routes and are not allowed to change them regardless of the actual traffic situation, and non-route vehicles, whose drivers are free to choose their route. Private vehicles make up the bulk of the traffic flow, and other vehicle types add congestion to the network [4].

Thus, volumes on all sections of the transport network are the condition of flows generated by the collective movement of drivers of vehicles that implement a known correspondence matrix [4].

When modeling the distribution of traffic flows along a road network, the model should include the goals set by the driver [5]. The driver's goal may be to minimize travel-related losses, such as travel time, energy expenditure, et cetera, and maximize their safety with the smallest deviation from comfortable conditions [6-9]. The possibility of traveling by different routes should also be taken into account.

The routes of each correspondence are determined by the correspondence following its interests [6]. According to researchers, there are still no reliable criteria to assess the decisions made by drivers to choose a route [10]. Extensive experiments are needed to find out the decisions that guide the driver when he chooses a route. It is also indicated that the most realistic criterion is the duration of the trip.

The possibility of using several alternative routes should be considered when building a system of shortest routes. One way is to determine all routes that differ from the shortest route by a constant, the value of which is selected for practical reasons [11].

The method based on designing route selection curves is widely known [6]. These curves are derived from observations and are based on using trip length or cost data. As a disadvantage of this method, it is necessary to note the possibility of distributing the traffic flow along only two competing routes. As a result, it is not suitable for large cities with a developed road network, where there are often more than two alternative routes.

It is possible to use the "direct distribution" method of trip distribution [2]. The model directly distributes traffic flows across network channels based on the density of trips on neighboring links. At the same time, one of the heuristic methods of flow overlay is used to count the traffic capacity: either iterative or sequential (stepwise) load increase [13]. The calculations are carried out until the equilibrium is determined. These methods ensure equilibrium in the network [14]. It is based on the assumption of driver behavior that drivers choose such routes that the total travel time for the entire system is minimized [13, 14]. However, the iterative procedure is too complicated and cannot produce convergent results. Instead, it is proposed to use the principle of maximum weighted entropy to model the mass behavior of a homogeneous mass of people.

The route choice can be influenced by random factors such as weather, mood, time, health, et cetera. As a result, according to some researchers, the decision-making model should be based on the probabilistic principle [15].

The reviewed sources make it clear that a large number of studies are devoted to the distribution of traffic correspondences on alternative routes, and the purpose of these researches was to forecast the volume of correspondences on sections of the city's road network. The disadvantages of existing methods, models, and algorithms for distributing traffic over the road network include the fact that the strategy for choosing a route among possible and real-time traffic conditions on the network is not taken into account to the fullest extent. It is due to the leading role of a person in the process under consideration, and it is difficult to evaluate the actions and decisions of a person. In such circumstances, it is worth supplementing the existing research results with drivers' opinions when choosing routes. Since the problems of drivers' route choice need to be studied in the field for further forecasting, the study presented in this article is relevant.

Based on the analysis of the issue, the purpose of the study is to determine the distribution patterns of transport correspondences along alternative routes.

The object of the study is traffic on the city's road network.

The following tasks need to be solved to achieve the research purpose:

– carry out a field study to determine the entire set of criteria used by drivers in comparing the characteristics of alternative routes;
– obtain information about the routes that drivers use when traveling between points of origin and destination;
– to obtain patterns of distribution of transport correspondences along alternative routes.

The expected results of the conducted research and their analysis are the basis for the law of distribution of traffic correspondences along alternative traffic routes for further study of the patterns of traffic flow formation in cities.

3. DESCRIPTION OF THE RESEARCH OBJECT AND METHOD OF ITS IMPLEMENTATION

Non-route transport is operated on different routes, and the choice of a particular route depends on the decisions made by drivers, which consider their specific characteristics. This dependence can be represented as the following function:

$$h_{ij}^{k} = f(l_{ij}^{k}, t_{ij}^{k}, K_{ij}^{k}, B_{ij}^{k}, ...), \qquad (1)$$

where h_{ij}^k – the amount of correspondence distributed along the *k*-th route of movement; l_{ij}^k – the length of the *k*-th route; t_{ij}^k – the travel time between the *i*-th and *j*-th districts along the *k*-th route; K_{ij}^k, B_{ij}^k – respectively, the level of comfort and safety of movement along the *k*-th route.

The graphical distribution of transport correspondences by alternative routes is shown in Fig. 1. Drivers use different criteria in their decision-making, which makes it necessary to identify these criteria and assess their significance.

The authors developed a questionnaire (Fig. 2) and carried out a survey that recorded the route data and determined the significance of the criteria used in route selection to determine the patterns of route selection by drivers.

According to [16], for a value with a probability of 0.95 and a margin of error of 0.05, the number of observations is 384. In this regard, 400 questionnaires were filled out during the survey.

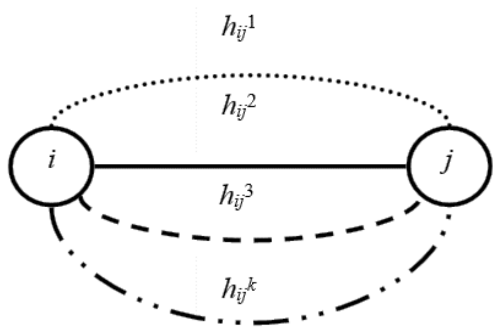


Fig. 1. Scheme of transport correspondence between the city districts by alternative routes: i – district of departure. j – district of arrival.

Date of the survey ________
Driver __________________

Points of departure and destination		*Route track*	*Frequency of route use, %*	*Criteria for choosing a route*	*Travel time along the route*
from	*to*				
		1.			
		2.			
		3.			

Criteria for choosing a route: 1) route length; 2) travel time; 3) level of comfort; 4) safety of movement.
Rank the importance of the following criteria from the most important, in your opinion, to the least important___________________________________

Fig. 2. Questionnaire for surveying the route of drivers

4. MAIN PART

The first stage of the research was to recognize the weight contribution of the selected criteria. For this purpose, we used the method of rank correlation, i.e., a priori ranking based on the assessment by a group of experts [17]. Drivers of off-route vehicles were used as experts, as they were the ones who decided to choose a route.

The survey was conducted in Kharkiv. In the prewar period, the city's population was 1430885 inhabitants, the total length of roads was 1368.5 km, and the density of the road network was 3.91 km/km^2. In Kharkiv, 191739 vehicles were registered, which determined the level of motorization of 134 cars/1000 persons. Processing of the survey results showed that travel distances ranged from 6.1 to 36.5 km. Calculation results showed that the sum of the ranks of the factors studied varied from 1347 for the most significant to 2346 for the least.

According to the survey results, the most essential factor is the minimum mileage along the route. The next stage of survey data processing was carried out to determine the patterns of distribution of correspondence of non-route vehicles along alternative routes, in which the deviation from the shortest route was calculated using the formula:

$$\Delta_i = \frac{L_i - L_{\min}}{L_{\min}} \cdot 100\%, \tag{2}$$

where Δ_i – deviation from the shortest route by length, %; L_i – the length of the *i*-th design route, km; L_{min} – length of the shortest route, km.

The distribution of transport correspondences along alternative routes, depending on their deviation from the shortest route, was determined by the following relationship:

$$P_j = \frac{\sum v_i}{v_z}, \tag{3}$$

where P_j – the share of drivers who use routes that deviate from the shortest one Δ_i; v_i – number of trips along the route with deviations from the shortest route Δ_i; v_z – the frequency with which the entire set of routes is used, which is calculated using the formula:

$$v_z = n, \tag{4}$$

where n – total number of transport correspondences.

The results of the calculations are shown in Table 1. If we assume the volume of departures from district *i* to district *j* to be 100 %, we get the following distribution of transport correspondences along alternative routes, depending on the deviation in length from the shortest route.

Table 1

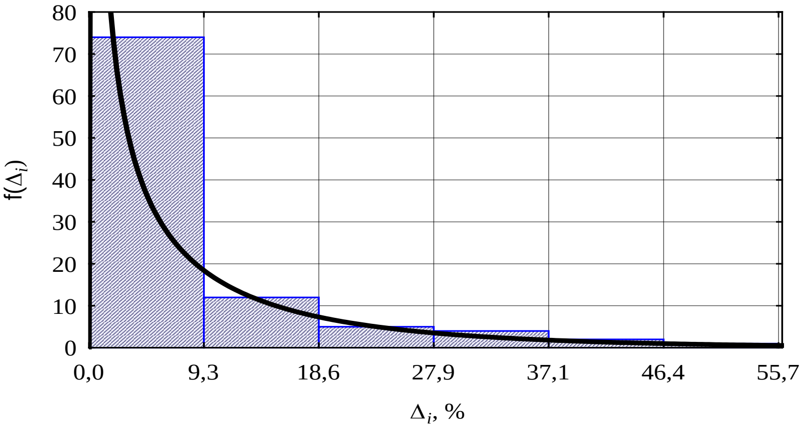
Distribution of transport correspondence by alternative routes

Δ_i, %	0	1–10	11–20	21–30	31–40	41–50
P_i	0.569	0.165	0.118	0.051	0.036	0.021
Δ_i, %	51–60	61–70	71–80	81–90	91–100	101–200
P_i	0.011	0.0062	0.0056	0.0039	0.0011	0.0029

Because the process under consideration is probabilistic in nature, it becomes necessary to determine the distribution law of a random variable. The consistency of the empirical and theoretical distributions was assessed using Pearson's agreement criterion for a confidence level of $P = 0.95$ and an error margin of $\varepsilon = 0.05$ [16].

When determining the law of distribution of a random variable for the data obtained, the calculations showed that the change in the random variable is well described by the gamma distribution (Fig. 2).

Fig. 2. Histogram and density of distribution of deviation of transport correspondence from the shortest route



The calculated value of Pearson's criterion was 0.364, and the tabulated value was 0.714. The tabulated value of Pearson's agreement criterion exceeds the calculated one, which indicates the consistency of the empirical and theoretical distributions.

The density of the gamma distribution is as follows [17]:

$$f(t,\ \eta,\ \lambda) = \begin{cases} \dfrac{\lambda^{\eta}}{H(\eta)}\ t^{\eta-1}\ e^{-\lambda t} \\ t \geq 0,\ \ \lambda \succ 0,\ \ \eta \succ 0, \\ 0\ \text{ in other cases} \end{cases} \tag{5}$$

where η – form parameter; λ – scale parameter; $H(\eta)$ – known gamma function.

As a result of the calculations, the following values of the distribution parameters were obtained: η=0.339, λ=0.049.

The histogram and density of distribution of the deviation of transport correspondence from the shortest route are shown in Fig. 2. Thus, as the length of the route deviates from the shortest one, the share of transport correspondence that will be carried on them decreases.

After determining the regularity of the distribution of transport correspondence, it became possible to analyze this distribution along alternative routes to assess the possibility of using the route length as a criterion.

It is necessary to compare the actual values of transport correspondence with the estimated values to assess the adequacy of the distribution of transport correspondence. Research was conducted to identify them to obtain real-time data.

The first step was to define the study area and identify the points of departure and destination located at different distances from each other. For ease of orientation, intersections were used as departure and destination points. It was followed by a survey of drivers who regularly travel in the area. All the necessary information about the driver and the vehicle was entered into a special card. Then, the driver was required to indicate the route he would take between the proposed points. The condition was set that the traffic was carried out during the morning rush hour. The routes indicated by the drivers were mapped. As a result of the survey, 112 drivers were interviewed, and 387 correspondences were recorded.

The survey revealed a characteristic feature of route selection, which is that drivers deliberately exclude some possible alternatives when making a decision due to unsatisfactory traffic conditions (road surface conditions, various traffic obstacles).

The next step was to process the survey data, which consisted of summarizing the correspondence along the same routes. As a result, data was obtained on the amount of correspondence and its distribution along alternative routes. Then, their length was measured for each route.

After the actual distribution of correspondences along alternative routes was determined, it became necessary to obtain their estimated values. For this purpose, a distribution algorithm was developed and modeled.

Since drivers do not accurately determine the distance, the concept of a threshold value was introduced, i.e. the minimum increase in the length of the route perceived by the driver. Thus, if several routes have deviations within the same interval, the correspondence between them is distributed evenly.

The average error of deviation of the calculated value from the actual value was calculated to compare the values of correspondence distributed along alternative routes according to the "route length" criterion. The average error was 16.02 %. The path length is only a spatial characteristic and does not reflect traffic conditions such as the number of lanes, traffic volume, intersections, and delays associated with traffic flow. It determines a large distribution error.

5. CONCLUSIONS AND RESEARCH PERSPECTIVES

This work aimed to study the regularities of the distribution of vehicle correspondences on the road network of cities through the prism of random variables. Most scientific works on this topic are aimed at predicting traffic flow parameters using objective factors. However, the subjective factors of drivers' route choices were not fully considered.

The object of the study was the process of choosing routes by drivers when traveling in the city. The criteria for selecting traffic routes were evaluated based on the results of field surveys by interviewing drivers. At the same time, the criteria for choosing routes and the actual routes of movement in the city were determined. We used probabilistic methods, namely the law of distribution of a random variable, to evaluate the route selection results.

It was found that the distribution of flows of non-route vehicles along alternative traffic routes depends on their characteristics, one of which is the length of the route. Most correspondences are made via the shortest routes. When drivers determine a route, the probability of making correspondence on routes with a minimum length exceeds 0.5. More than 90 % of the selected routes are within 50 % of the deviation from the routes that provide the minimum value of this parameter. At the same time, the distribution of transport correspondences along alternative routes is consistent with the gamma distribution. As a result of the calculations, the following values of the distribution parameters were obtained: η=0.339, λ=0.049.

The obtained results make it possible to predict road network congestion by modeling the distribution of traffic flows. In further research, it would be advisable to analyze the distribution of transport correspondences by other criteria.

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ДОСЛІДЖЕННЯ РОЗПОДІЛУ КОРЕСПОНДЕНЦІЙ ТРАНСПОРТНИХ ЗАСОБІВ ВУЛИЧНО-ДОРОЖНЬОЮ МЕРЕЖЕЮ МІСТ

Анотація. *Проблеми управління дорожнім рухом у великих містах ускладнюються тим, що збільшення інтенсивності руху транспортних засобів істотно перевищує пропускну здатність вулично-дорожньої мережі. Це призводить до насичення вулично-дорожньої мережі, що негативно позначається на її функціонуванні. В цій статті наведено аналіз питання щодо поліпшення якості дорожнього руху за рахунок прогнозування інтенсивності руху після упровадження заходів із організації руху транспортних засобів. Якщо питання моделювання параметрів транспортних потоків з технологічних факторів є досить вивченим, то проблеми врахування людського чинника потребують уточнення. Об'єктом дослідження у роботі є потоки транспортних засобів на вулично-дорожній мережі міста. За результатами натурного обстеження визначено критерії, які використовують водії для порівняння характеристик альтернативних маршрутів руху. На основі отриманих даних сформовано параметри альтернативних маршрутів, які водії вибирають, рухаючись вулично-дорожньою мережею. Як показали результати обстеження, найзначущішим фактором є мінімальний пробіг по маршруту. З метою визначення закономірностей розподілу кореспонденції немаршрутних транспортних засобів за альтернативними маршрутами руху визначено відхилення від найкоротшого маршруту. Це дало змогу визначити розподіл транспортної кореспонденції за альтернативними маршрутами руху. Оскільки розглянутий процес є імовірнісним, визначено закон розподілу випадкової величини. Під час визначення закону розподілу випадкової величини для отриманих даних у результаті обчислень з'ясовано, що зміна випадкової величини доволі добре описується гамма-розподілом. Встановлено, що зі збільшенням відхилення довжини маршруту від найкоротшого зменшується частка транспортної кореспонденції, яка на них здійснюватиметься. Отримані результати дають змогу надалі прогнозувати завантаження вулично-дорожньої мережі за допомогою моделювання розподілу потоків транспортних засобів. У подальших дослідженнях доцільно проаналізувати розподіл транспортних кореспонденцій за іншими критеріями.*

Ключові слова: *інтенсивність руху; транспортний потік; водій; відстань; маршрут руху; швидкість руху.*